Why Current Decay on a Wire Causes Radiation

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***Abstract*—The decay of current with increasing distance from the feedpoint of a straight wire antenna comprised of a perfect electric conductor has been attributed to radiation by numerous authors, e.g. [1-5]. This connection is explained here using a time-domain solution for an impulsively excited wire and relating this to the E-field kink model of radiation.**

I. INTRODUCTION

Attributing radiation to current decay appears to be a plausible explanation since an attenuated current would seem to be carrying less power or energy as a function of distance down a wire antenna. Less often mentioned as an explicit cause of current decay is a continuous reflection of the charge being carried by an outward-propagating current wave [6]. Little has been said about how and why this charge reflection could cause the electromagnetic radiation attributed to the decaying current. These topics are explored here to demonstrate how such an object can radiate along its length, contrary to claims made in some accounts [7-8].

II. CHARGE REFLECTION AND CURRENT DECAY

An examination of current decay in the time domain is possibly more revealing than in the frequency domain because it separates effects in time that might otherwise be obscured. For example, the charge-density pulses multiplied by the speed of light, c, on a wire excited at its center by a Gaussian voltage pulse shown in Fig. 1 produces a continuous, broadside far-electric field between the source and end-reflected far-field pulses depicted in Fig. 2. Observe that the radiated electric field has an initial pulse due to the source excitation and a second pulse due to end reflection. In between there is a continuous, decaying field that is the primary point of our discussion.

The negative parts of the charge and current pulses on the right-hand half of the dipole are shown in an expanded plot in Fig. 3 for several time steps. Whereas the positive right-hand current and charge pulses overlap in Fig. 1 their negative parts do not do so in Fig. 3. The current exceeds Qc where they are both negative. This is because the positive charge density, Q^{+}_{ref}, reflected from the rightward traveling pulse, results in a negative current. A negative charge, Q^{-}_{ext}, extracted from the source region by positive charge farther out on the right half of the antenna also constitute a negative current as given by

$$I^{-} = -Q^{+}_{ref}c - Q^{-}_{ext}c$$

where the net charge density is

$$Q_{net}c = Q^{+}_{ref}c - Q^{-}_{ext}c. \qquad (1)$$

Equations (1) and (2) can be used to find Q^{+}_{ref} and Q^{-}_{ext}. Alternatively Q^{+}_{ref} can be obtained by subtracting integrals of successive rightward propagating charge pulses with results for each compared in Fig. 4. The noisy appearance of the latter comes from the subtraction process. This small, partial reflection of the propagating charge pulse causes the current and charge decay shown in Figure 1.

This reflection demonstrates that the wave impedance presented by the wire does not match that of the propagating pulse. One explanation for this has been given [6] to the effect that the wire admittance varies with distance. Whatever the reason, current decay along a wire is observed in both the frequency and time domains.

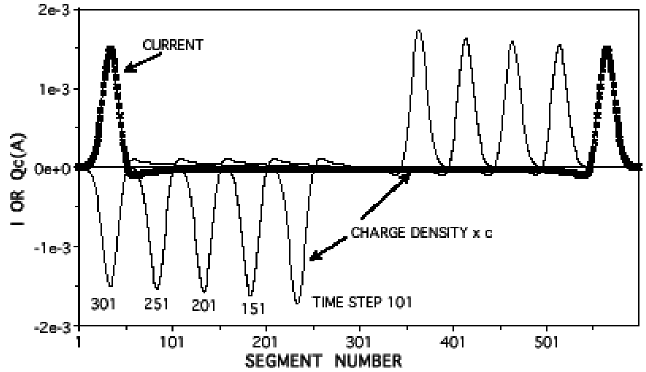

Fig. 1. Charge density times light-speed c for a 599-segment wire at several time steps and the current at time step 301.

III. CURRENT DECAY AND RADIATION

The reflection of the positive charge and extraction of the negative charge causes them both to be accelerated. This acceleration produces kinks in their electric field lines in accordance with the E-field kink model. The result is to produce 1/R outward-propagating electric fields as kinks in their field lines. But being of opposite sign and being accelerated in opposite directions their radiation fields are the same polarity, and are thus additive.

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Radiation from the partially reflected charge along the wire is qualitatively the same as the radiation that occurs when the entire pulse reflects from the open end of the wire. The amount of radiation in the former is less because less charge is involved. Note also that acceleration of the extracted charge involves a velocity change of c whereas the reflected charge undergoes a velocity change of 2c.

The broadside radiated field in the time interval between the source and end-reflection peaks is plotted in Fig. 5. Also shown is the sum of the extracted and reflected charge, the latter normalized to the center value of the far field. These two quantities exhibit very similar time behavior to thereby demonstrate the connection between the accelerated charge and the radiation it causes.

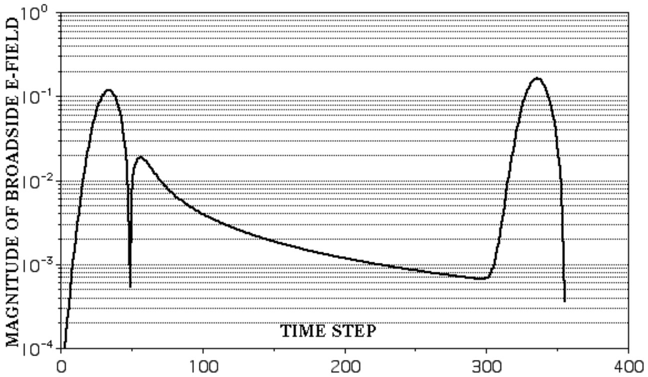

Fig. 2. Magnitude of the broadside field versus time step.

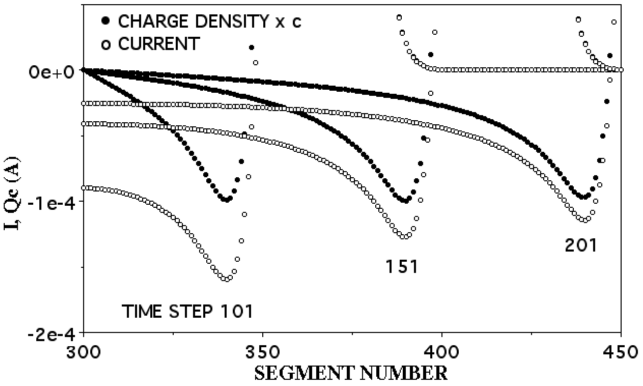

Fig. 3. Expanded negative parts of current and charge pulses for three time steps.

IV. CONCLUDING COMMENTS

The current decay that occurs as a pulse propagates down a long wire has been shown to be caused by its parial reflecion with distance along the wire. This reflection in turn causes radiation due to the charge acceleration that results.

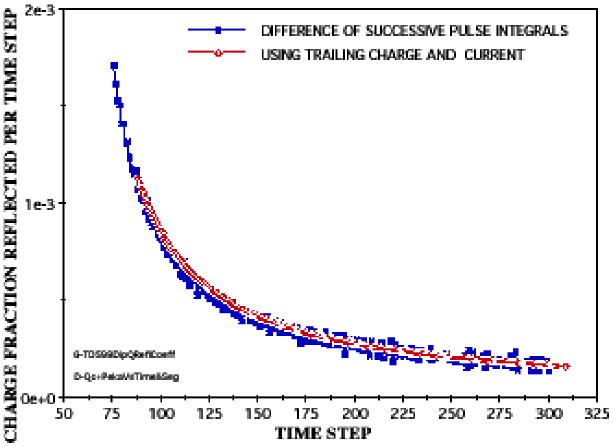

Fig. 4. The fraction of the outward-propagating charge pulse reflected per time step.

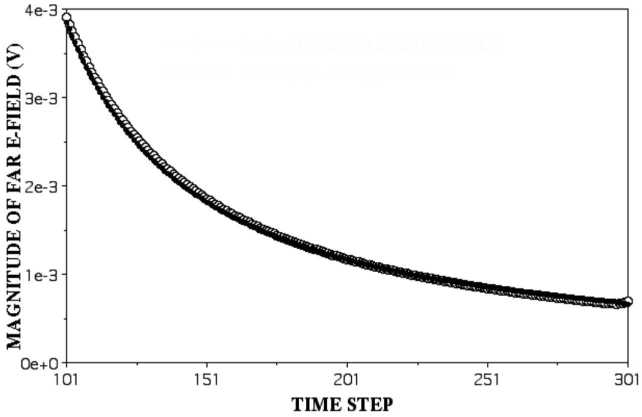

Fig. 5. Correlation between broadside radiation (o) and normalized accelerated charge (•).

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